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DOES SHORT-TERM PRACTICE ATTENUATE INITIAL CODING DIFFERENCES?

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attentuated across Blocks 2, 3 and 4. Although all coding conditions benefitted from practice, the benefit was more pronounced for partially-redundant color-coding.

Response-accuracy

Three percent of all responses were incorrect. Although a significant Code X Block interaction was found, $F(9,63)=2.12$, $p<.04$, the effects of coding across blocks were uninterpretable and appeared to be spurious. For that reason they will not be discussed further.

DISCUSSION

This discussion will be restricted to the attenuation of initial coding differences as a function of practice. No attempts will be made to explain why certain coding variables were more effective than others.

Experiment 1

For RT, the initial superiority of the color-coded conditions over the shape-coded conditions became less pronounced with practice, across all levels of density. This was primarily because the shape-coded conditions showed a greater degree of improvement in RT with practice compared to the color-coded conditions. Also, practice attenuated initial coding differences for accuracy measures, owing primarily to a large increase in accuracy for the shape/filled condition.

A possible explanation for the above effect follows. It has been well established that color is processed in parallel, and thus, color information can be extracted simultaneously (Gummerman, 1975; Luria & Strauss, 1975; Saraga & Shallice, 1973). In other words, color acts as an automatic segregating mechanism (Davidoff, 1984). Shapes, on the other hand, must be searched sequentially, resulting in slower search-times. Shiffrin and Schneider (1977) argued that, with practice, sequentially-processed information can be processed in parallel. Thus, with enough practice, the initial advantage of color eventually applies to shape-coding and any existing differences due to coding are attenuated.

Experiment 2

Counter to expectation, initial coding differences for RT were not attenuated with practice. For the search task, coding differences actually became more pronounced with practice, owing

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Does short-term practice attenuate initial coding differences?

Rebecca M.T. Jubis

Abstract

Three experiments that examined whether short-term practice would attenuate initial differences among coding conditions are reported. Experiment (Exp.) 1 showed that differences among coding conditions became less pronounced with practice for measures of response-time (RT) and accuracy. This was due primarily to a greater degree of improvement with achromatic shape-coding compared to color-coding.

Exps. 2 and 3, which used a more difficult task, showed that for an identification task, practice generally improved RT and reduced differences among coding conditions. For a search task, practice enhanced RT with color-coding conditions, but impaired RT with shape-coding. This impairment presumably reflected fatigue effects induced by the most difficult coding condition.

It was concluded that under certain task conditions, practice attenuated initial coding differences. These findings have important implications for the design and application of different codes in visual displays where short-term versus long-term enhancement of performance is the major objective and where training costs are of concern.

INTRODUCTION

Although the literature reporting the effectiveness of color- versus shape-coding for visual displays is large, few studies have examined whether practice reduces initial differences in performance due to coding conditions. Such research is necessary for determining the effectiveness of different coding conditions in relation to training costs. The present study examined whether short-term practice would attenuate any initial differences among shape- and color-coding conditions.

The few studies that have examined the effects of color- and shape-coding as a function of practice will be briefly presented below. Christ and Corso (1975) reported studies that evaluated the effectiveness of colored dots compared to achromatic letters, digits and shapes in a choice reaction-time task. The results showed that choice reaction-time was faster for digits than for other code sets. Although the authors reported that differences among code sets decreased with practice in these experiments, the Code X Practice interaction was not significant.

Christ and Corso (1983) presented a summary of nine experiments, each of which used the same stimuli as Christ and Corso (1975). The same subjects participated in all experiments and were described as being highly practiced. The results provided no evidence that any one code was superior to any other. The authors concluded that extensive practice attenuated any initial differential effects of coding on performance. The validity of this conclusion is questioned, however. Practice effects across experiments were confounded with the type of task employed and with other display characteristics, and it has been previously well-established that the effectiveness of different codes is very dependent upon task-type and other task variables (Christ, 1975; MacDonald & Cole, 1988).

Najjar, Patterson and Corso (1982) used a signal-detection paradigm to examine the relative effectiveness of redundant color, partially-redundant color, nonredundant color, and monochrome shapes in a visual search task. They reported that although coding had no effect on response-time (RT) measures, it interacted with practice for measures of accuracy. This interaction was due to a relatively large increase in accuracy with monochrome shapes, as a function of practice.

In an air-traffic control simulation altitudes were either redundantly color-coded or achromatically coded (Patterson, Engelman, Najjar and Corso,1984). Practice led to a decrease

in search time but did not affect accuracy. There was no evidence of a Code X Practice interaction.

Finally, Wagner (1977) measured the ability of subjects with varying degrees of experience to detect malfunctions that were either color-coded or black-and-white in an engine-mangement display, while simultaneously detecting targets in an adjacent TV display. The first experiment found no difference in performance between naive subjects and subjects who had experience in target-acquisition studies. The second experiment compared performance of four groups: civilians with experience in target-acquisition studies, civilians without experience in such studies, experienced military pilots and navigator officers, and inexperienced enlisted military men. Experience did not interact with coding effects. Unfortunately, the author failed to report the degree to which subjects were experienced.

In summary, it has not been firmly established that practice or experience attenuates differential effects of coding on performance. Only Najjar et al. (1982) actually obtained a significant interaction of code and practice, and this applied only to measures of accuracy and not response-time.

This purpose of this paper was to test the hypothesis that short-term practice would attenuate or reduce initial differences in performance due to different coding conditions. All of the above-mentioned studies used projected or reflected targets rather than a CRT display. Also, the only study to utilize a task that simulated a realistic operational task was by Patterson et al. (1984). Consequently, generalizations from past studies to situations that involve more realistic and current displays are questionable. In contrast to earlier studies, the present experiments displayed stimuli on a CRT display and utilized a realistic process-control task. Although the general experimental procedures remained the same across all three experiments, these experiments differed in terms of coding condition, code-set size, and number of system parameters.

EXPERIMENT 1

Redundant color-codes (color and shape were perfectly correlated) were compared to achromatic shape-codes for coding the operational states of targets in a process-control task, under different levels of display densities (the number of targets displayed) with search and

identification tasks. This study also compared the effectiveness of two different sets of geometric shapes, each under color and achromatic-shape conditions. One set used "filled" shapes (solid squares, triangles, diamonds) and the other used "hatched" shapes (hollow squares, hollow squares with a horizontal line, hollow squares with two diagonal lines).

GENERAL METHOD

Subjects

The subjects were twelve, naive, paid volunteers with normal color vision and normal or corrected visual acuity.

Design

The study used a within-subject design and all of the following were within-subject factors: coding scheme (colored "filled" shapes, colored "hatched shapes", achromatic "filled" shapes and achromatic "hatched" shapes), task (identification and search), and display density (12, 16, or 20 simultaneously displayed targets). Dependent measures were RT and accuracy of responses to statements concerning the states of the targets.

Subjects were tested under all four coding conditions, each presented on a different day in a balanced Latin-square design. In each condition, subjects were tested on four blocks of 36 trials. Practice effects were based upon comparisons across these four blocks, particularly between the first and last block. Trials within blocks were balanced for equal presentation of each task-type and display density, so that six observations for each combination were presented per block.

Display

The stimuli were programmed and displayed on a Sun-3/110 color workstation. Subjects were presented with a process-control engine-diagram containing either 12, 16, or 20 vertically-positioned targets, that were labeled with letters of the alphabet.

A target could be in one of three possible states: normal, warning and alarm, and each was coded according to the given coding conditions.

Subjects viewed 6-mm high symbols displayed on the CRT, from a distance of approximately 50 cm, producing a visual angle of about 43 minutes of arc. The average

respective illuminances on the computer keyboard and CRT were 67 lx and 10 lx, and the average background luminance and target luminance were 0.7 cd/m^2 and 5 cd/m^2, respectively. The display background was black under all coding conditions.

Procedure

Prior to each testing session, subjects completed 36 practice trials designed to familiarize them with the symbology. This was followed by 18 practice trials that consisted of a sample of actual experimental trials. Subsequently, subjects underwent four blocks of 36 trials, for a total of 144 trials. On a given trial, a statement (see below) was displayed at the bottom of the CRT display simultaneously with a computer-generated auditory tone. Subjects were told to press the spacebar after having read and understood the statement. This terminated the statement and displayed the process-control diagram. Based upon the information in the diagram, subjects indicated whether the statement was true or false by pressing the "t" or "f" key respectively.

The search task, which was similar to a counting task, was characterized by a statement such as, "There are three targets in alarm." The identification task, on the other hand, was less general in that subjects were required to identify the state of specific targets on the basis of their alphabetical label in order to respond to the statement. A characteristic statement would be, "Targets C and D are in alarm."

A maximum of three targets randonly-selected were searched or identified on a given trial. The "normal" state was considered the default state and only states of "alarm" and "warning" were included in the statements to which subjects responded. On a given trial, a maximum of three displayed targets could acquire a state other than "normal". Thus, with densities of 12, 16 and 20, the percentages of targets that were displayed in a "normal" state on any given trial were at least 75, 81 and 85, respectively.

RESULTS

The following were included as within-subject factors in an analysis of variance (ANOVA): subject (12), coding condition (color/filled, color/hatched, shape/filled, shape/hatched), block (1,2,3,4), task (search, identification), and density (12,16, 20). Each combination of the last two factors was averaged over six trials per block. As the aim of this paper was to

determine the effects of practice on the extent of coding differences, only significant interactions that included both "code" and "block" as factors are presented. Post-hoc comparisons were Tukey tests at the 0.05 level of significance.

Response-time

From an ANOVA performed on RT for correct responses, a significant Code X Density X Block interaction was found, $F(18,198)=1.74$, $p<.04$ (see Figures 1, 2, and 3). Across all levels of density and block, RT was faster with color/filled or color/hatched conditions compared to shape/filled or shape/hatched conditions. It should be noted, however, that the difference between the color conditions and the achromatic conditions was greater in Block 1 than in Block 4. Furthermore, practice led to a greater degree of improvement in RT measures in the shape-coding conditions than in the color-coding conditions.

Response-accuracy

Only 3.5% of all responses were incorrect. An ANOVA performed on the percentage of correct responses revealed a significant Code X Block interaction, $F(9,11) = 2.00$, $p<.05$ (see Figure 4). Across Blocks 1 to 3, the shape-filled condition led to fewer correct responses compared to the other coding conditions. These conditions no longer differed in Block 4, primarily due to an increase in accuracy at Block 4 for the shape-filled condition. In line with Najjar et al. (1982), practice improved accuracy only in the shape/filled condition.

EXPERIMENT 2

Eight naive subjects participated in Exp. 2, which compared the effectiveness of four methods of coding: a) achromatic shape-coding, b) redundant color-coding (shape and color were perfectly correlated), c) nonredundant color-coding (shape was held constant but colors differed), and d) partially-redundant color-coding (targets differed in terms of color and shape but only shape was unique to the target).

The "system parameter" being monitored was temperature level, and targets could acquire four possible states: low, normal, moderate, and high. Codes for each state in each coding condition were as follows in the respective sequence:

a) redundant color: blue triangle, green square, orange cross, red diamond,

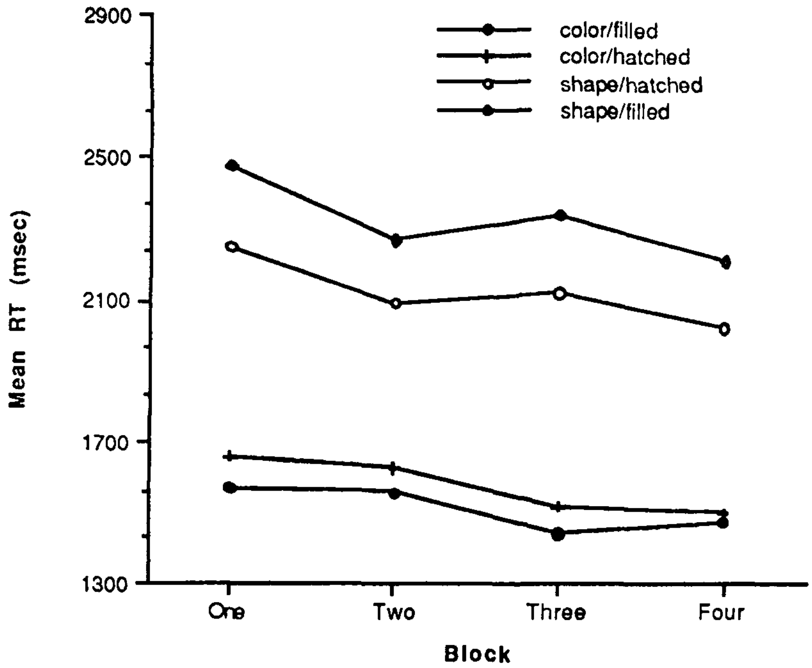

Figure 1. Coding effects on RT as a function of practice with a display density of 12.

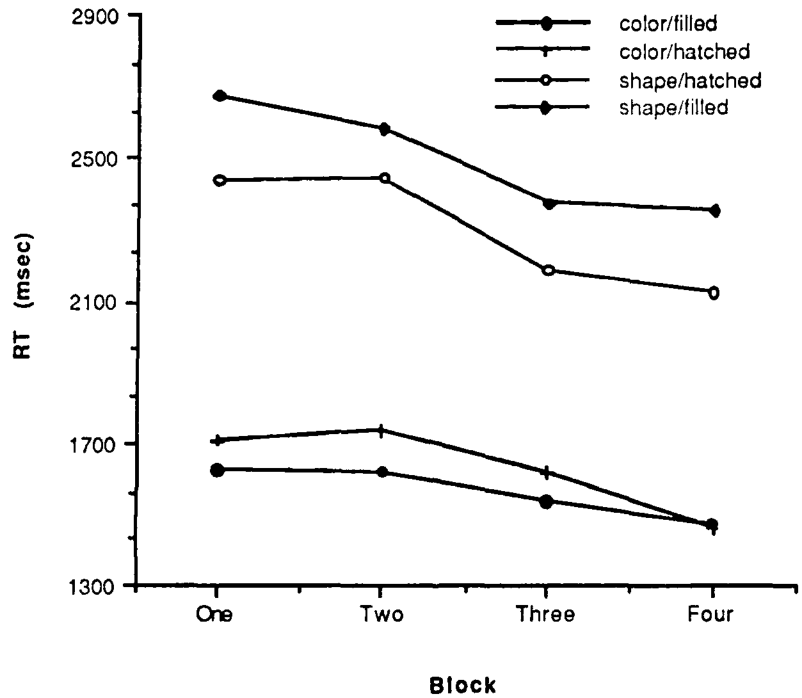

Figure 2. Coding effects on RT as a function of practice with a display density of 16.

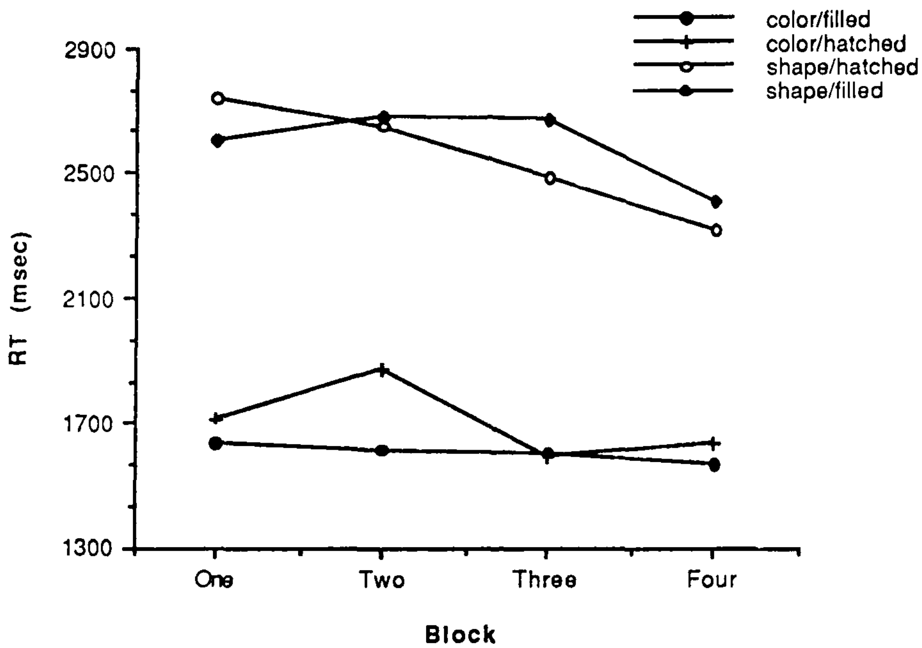

Figure 3. Coding effects on RT as a function of practice with a display density of 20.

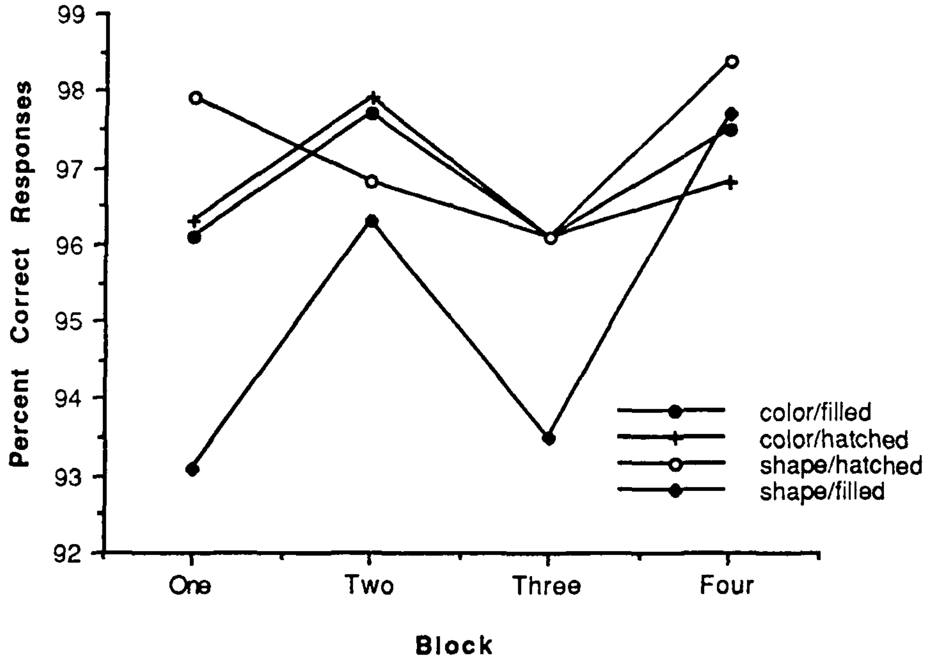

Figure 4. Coding effects on response-accuracy as a function of practice.

b) nonredundant color: blue, green, orange, and red squares,

c) partially-redundant color: green triangle, green square, red cross, red diamond,

d) achromatic shapes: white triangle, square, cross and diamond.

Other experimental variables and procedures were the same as in Exp. 1.

In Exp. 1, targets could acquire three states, but only two of these states were included in the statements to which subjects responded. In this experiment, targets could acquire four states, all of which could appear in the statements. Furthermore, on a given trial, the number of targets that acquired a particular state never exceeded 35% of the total number of targets displayed. In Exp. 1, on the other hand, 75%-85% of targets acquired a "normal" state on any given trial.

RESULTS

Response-time

An ANOVA performed on RT for correct responses revealed a significant Code X Task X Block interaction, $F(9,63)=4.18$, $p<.0003$. For the search task, RT was faster with redundant color-coding and nonredundant color-coding compared to partially-redundant color-coding or shape-coding, and RT was faster with partially-redundant color-coding than shape-coding. Furthermore, the differences between shape-coding and other coding conditions were considerably greater in Block 4 compared to Block 1. Practice led to improved RT performance for redundant color-coding and nonredundant color-coding, and had no effect on RT for partially-redundant color-coding. With shape-coding, RT performance became progressively worse with practice (see Figure 5).

For the identification task, all coding conditions improved with practice. Although practice reduced initial differences among coding conditions, these initial differences in coding were not statistically significant.

Response-accuracy

An ANOVA was performed on the percentage of correct responses, and no significant main effects or interactions involving code or block were found. Only 2.04% of all responses were incorrect.

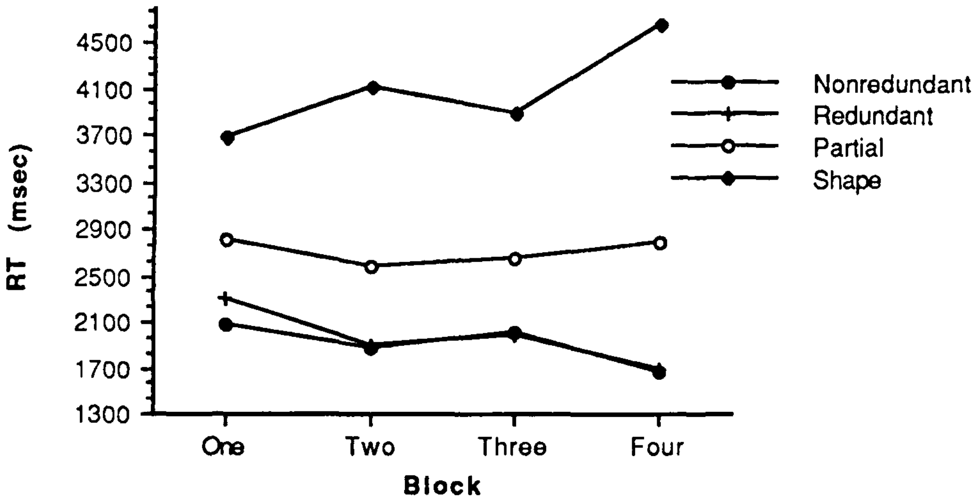

Figure 5. Coding effects on RT as a function of practice for the search task

EXPERIMENT 3

Because complex process-control systems require the operator to monitor large amounts of information, coded information pertaining to the states of different system sources may be presented on the same process-control diagram. The following experiment attempted to examine the interaction of coding variables and practice using a multi-parameter display.

The same set of eight subjects from Exp. 2 participated in Exp. 3. The only difference between Exps. 2 and 3 was that in Exp. 3 two system parameters were involved (rather than one), each of which could acquire two states: a) temperature, whose state could be "high" or "low", and b) oil, whose state could be "full" or "empty". The manner in which temperature/high, temperature/low, oil/full and oil/empty were coded for each coding condition was as follows, respectively:

a) redundant color: red diamond, blue triangle, green square, orange cross,

b) nonredundant color: red, blue, green, and orange squares,

c) partially-redundant color: red diamond, green triangle, green square, red cross,

d) achromatic shapes: white diamond, triangle, square, and cross.

RESULTS

Response-time

A significant Code X Task X Block interaction, $F(9,63)=4.18$, $p<.0003$ was found (see Figures 6 and 7). For the search task RT was faster with redundant color-coding and nonredundant color-coding compared to either partially-redundant color-coding or shape-coding, and faster with partially-redundant color-coding compared to shape-coding. This difference between shape-coding and other coding conditions was more pronounced in Block 4 compared to Block 1, owing primarily to a large increase in RT for shape-coding in Block 4. Practice enhanced RT performance for redundant color-coding and nonredundant color-coding, had little effect for partially-redundant color-coding, and degraded performance for shape-coding.

For the identification task, RT performance in Block 1 was worse with partially-redundant color-coding compared to the other coding conditions. However, these differences were

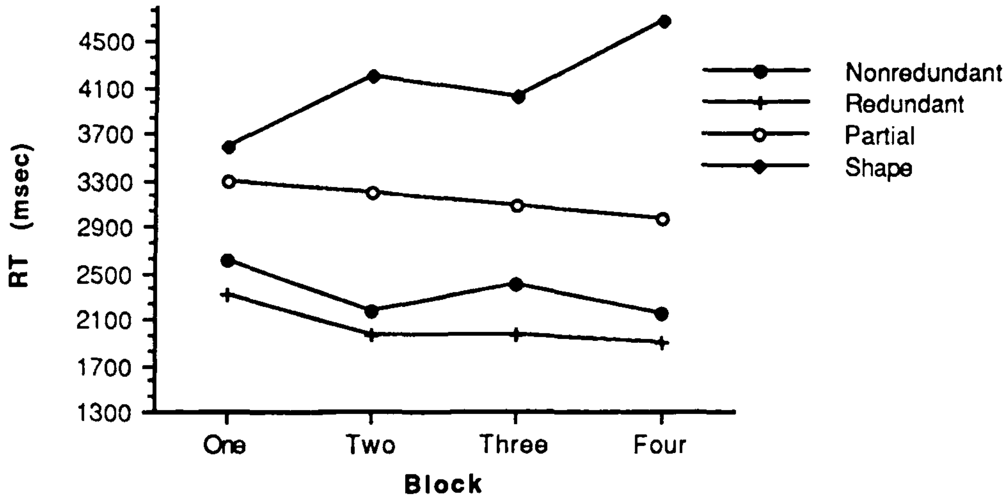

Figure 6. Coding effects on RT as a function of practice for the search task.

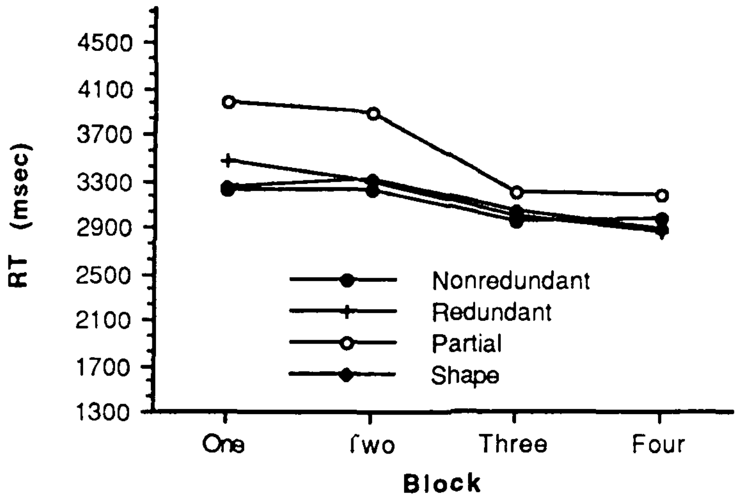

Figure 7. Coding effects on RT as a function of practice for the identification task.

to a dramatic increase in RT for shape-coding. A possible reason for this finding is that shape-coding, being the most difficult coding condition, led to fatigue, and in turn, led to a deterioration in performance over time. For the identification task, coding conditions did not differ either before or after practice.

Experiment 3

For the search task, in line with Exp.2, initial coding differences became more pronounced with practice, due to an increase in RT for shape-coding. For the identification task, in contrast to Exp.2 (which found no differences in coding either before or after practice), initial differences in coding disappeared with practice.

GENERAL DISCUSSION

A general conclusion that can be drawn from these three experiments is that short-term practice attenuates initial performance differences due to coding, but only under specific task-related factors. Some of the factors that appear to at least partially affect the above relationship are: coding condition, task-type, code-set size, number of system parameters, and performance measure.

The experimental findings upon which the above conclusion was based are as follows:

a) Practice decreased the initial differences in RT between color- and shape-coding conditions across all levels of display density (Exp. 1).

b) Initial differences among coding conditions for measures of accuracy disapeared with practice in Exp. 1.

c) For the identification task, with two parameters, initial coding differences for RT disappeared with practice (Exp. 3).

The paucity of research in this area, as well as the variability among existing studies make it difficult to make meaningful comparisons between the present and previous findings. Although some earlier studies have claimed that practice attenuates coding differences, these claims were not empirically substantiated. The only study that appeared to show a significant interaction of coding and practice was by Najjar et al. (1982), who reported that practice produced a relatively greater improvement in accuracy (but not RT) for shape-coding. It is not

clear why that study found no interaction of code with practice for RT, while the present experiments did. There were, however, a number of differences between the present experiments and the Najjar et al. study that could account for discrepant findings. For instance, Najjar et al. (1982) used a different type of task (subjects searched for a specified target that could appear in one of four quadrants and simply reported whether or not the target was present), they used a code-set size of five (as opposed to three or four in the present study), shapes and colors did not represent an underlying concept (such as system states), and practice effects were based upon only two blocks each of 40 trials.

For the search task in Exp. 1, shape-coding showed the greatest improvement in RT as a function of practice. But for the search tasks in Exps. 2 and 3, shape-coding produced an impairment in RT performance, while RT for the other coding conditions either improved or showed little change. This impairment was presumably due to the fact that shape-coding, being the most difficult condition, led to fatigue and in turn impaired performance. It is still not clear, though, why practice led to impaired RT for shape-coding over time in Exps 2 and 3, while, as expected, it improved RT for shape-coding in Exp.1. A possible explanation for this discrepancy follows.

As mentioned earlier, in Exp.1 targets could acquire three states but only two of these states were included in the statements to which subjects responded (the third state was considered the default). Also, on any given trial 75%-85% of the targets were in the default state, and so, it was relatively easy to distinguish the targets in question from those in the default state. In contrast, targets in Exps. 2 and 3 could acquire four states, each of which could appear in the statements, and the number of targets in a given state could never exceed 35% of the total number of targets displayed. Thus, in Exps. 2 and 3 it was more difficult to search for the targets in question and distinguish them from the "non-targeted" targets because more colors were displayed at a given time.

In brief, the search task in Exps. 2 and 3 was considerably more difficult than in Exp.1, and the consequent fatigue effects outweighed any potential advantage of practice. An indication that the search task in Exps. 2 and 3 was more difficult than in Exp. 1 was that RT was considerably slower in the former than the latter two experiments. One important implication of these

findings is that the influence of practice on coding effects cannot be predicted by simply knowing which coding condition is being used. Rather, the relationship between practice and coding effects appears to be dependent upon other experimental conditions. These findings further suggest that not only should coding conditions be evaluated in light of practice effects, but also in light of fatigue effects. For instance, if a particular coding condition optimizes performance in the short-term, but leads to a relatively quicker onset of fatigue, or to a more pronounced effect of fatigue, then it may not be the optimal coding condition.

Exp. 1 showed that, for the search task, practice reduced initial differences for RT, across all densities. It should be noted, however, that although this interaction was statistically significant, the attenuation effect was small, and probably insignificant where practical considerations are concerned. Only more research can determine whether further extensive practice would lead to a greater attenuation effect that would ultimately lead to comparable performance across all coding conditions.

In the present experiments practice was determined on the basis of four continuous blocks of trials. Future research should examine whether similar findings would be obtained if the number of blocks per session were extended, if sessions were repeated over an extended period of time, or if the distribution of practice (massed versus distributed) would yield differential effects. Furthermore, it is important to determine whether practice effects are long-lasting or whether they quickly dissipate.

The results of the present study have important implications for the design and application of alternative coding conditions in visual displays. If short-term enhancement of performance is of primary interest and operators are relatively inexperienced, then the manipulation of coding conditions may serve to improve operator performance, and a careful decision must be made about which coding condition should be implemented. If, on the other hand, enhancement of long-term performance is the major objective and coding differences are minimized by extensive practice, then factors other than coding are probably more important for enhancing performance. Because long-term enhancement of performance is typically the ultimate objective, future research should be geared toward evaluating the effectiveness ofdifferent coding conditions on performance after extensive practice, and determining which coding

conditions show the quickest and greatest improvement with practice. Such knowledge is required when deciding upon which coding condition should be implemented in light of the costs and benefits associated with training.

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It was concluded that under certain task conditions, practice attenuated initial coding differences. These findings have important implications for the design and application of different codes in visual displays where short-term versus long-term enhancement of performance is the major objective and where training costs are of concern.

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